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TECHNICAL REPORT ARSCD-TR-79011

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A MINIMUM WEIGHT CARTRIDGE CASE DESIGN FOR 30 MM SEPARATE LOADED AMMUNITION (SLAMMO)

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A goal for weapon system designers is to minimize the total weapon system weight. This is particularly relevant for those weapon systems that are destined for installation in rotary-winged aircraft. One of the principal parameters by which the weapon system weight is controlled is configuration and weight of the individual cartridge.

In this report, the generalized analysis to determine the minimum weight cartridge case (and hence cartridge), given certain constraints such as wall and

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20. ABSTRACT (continued)

head thicknesses, and the propellant volume to be packaged is discussed. The analysis is initiated by the defining of the consolidated propellant charge required to produce a predetermined level of muzzle energy for the 30 mm Separate Loaded Ammunition (SLAMMO). The minimum cartridge case weight is then calculated by the evaluation of a generalized expression for the geometry of the case. This analysis is then applied to the cylindrically configured 30 mm SLAMMO cartridge case. Finally, additional factors are discussed that should be considered in the optimized design of cartridge cases.

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INTRODUCTION

In search of more effective weapons to counter future threats, consideration must be given to small caliber ammunition with higher muzzle velociti es, flatter trajectories, reduced times of flight, increased rates of fire, reduced cartridge size and weight, increased lethality, and higher l/d (length to diameter) ratio projectiles.

The aforementioned areas form the cornerstones of the first generation Future Automatic Cannon System (FACS) exploratory development that is projected for engineering development during the post-1985 time frame. FACS, as currently configured, will incorporate one of three contending ammunition concepts within a unique weapon system. These three concepts, known as Case Telescoped, Folded, and Separate Loaded Ammunition (SLAMMO), respectively, are each the product of several years of exploratory development (6.2).

This information was generated as part of the FY79 FACS program and, as such, specifically addresses the SLAMMO concept. The analyses and formulae used, however, are general and consequently can be applied over a broader spectrum.

APPROACH

The muzzle energy of a gun system is principally determined by the following parameters: propellant charge to mass ratio, peak chamber pressure, and expansion ratio. The results of this analysis will be used to determine the required consolidated propellant charge to achieve a certain level of muzzle energy for the 30 mm SLAMMO system. After the requisite propellant volume is established, a general solution is derived for the calculation of the cartridge case dimension by which the total cartridge case weight is minimized. This general solution, established on the basis of a given propellant volume and a given cartridge case head and wall thickness, is then applied to the 30 mm SLAMMO system.

ANALYSIS

Propellant Volume Determinations

The following 30 mm SLAMMO ballistic conditions (ref. 1) are used to determine the requisite propellant volume:

Muzzle velocity	1113 M/sec (3650 ft/sec)
Chamber pressure	413.4 MPa (60.0 Kpsi)
Barrel length	213.36 cm (84.0 in.)
Consolidated charge loading density	1.25 g/cm^3 (316.12 gr/in.^{3})
Projectile weight	324 g (5000 gr)

The required charge weight is determined by an empirical approach. As described in reference 2, a set of graphs was developed from firing data of a representative group of weapons relating charge to mass ratio, expansion ratio, and peak chamber pressure to muzzle velocity. These empirical graphs were subsequently fitted to suitable equations, and appropriate curve-fitting constants were calculated. Equation 1 was obtained in this manner. Reference 3 contains the following ballistic equation that will serve to predict the required propellant charge weight:

$$MV = \left[F\left(\frac{c}{m}\right)\right] \left[G(P)\right] \left[H\left(\frac{x}{xo}\right)\right] \text{ ft/sec} \qquad (1)$$

where the above functional relationships* are determined by

$$F\left(\frac{c}{m}\right) = 3213 \left(\log \frac{c}{m}\right) + 4120$$

$$G(P) = 0.545 \, (P)^{0.148}$$

$$H\left(\frac{x}{xo}\right) = 0.668 \left(\frac{x}{xo}\right)^{0.25}$$

and

c = Mass of Propellant Charge (gr)

m = Mass of Projectile (gr)

P = Peak Chamber Pressure (Kpsi)

$\frac{X}{Xo}$ = Expansion Ratio = $\frac{(x)\ (A) + Vc}{Vc} = \frac{(x)\ (A) + Vp}{Vp}$

A = Bore Cross-Sectional Area (in.^{2})

x = Projectile Travel (in.)

V_c = Chamber Volume (in.^{3})

*These equations have been formulated for the English system of units; conversion of these equations to metric units cannot be done because of the nature of the curve-fitting constants and exponents.

Vp = Propellant Volume (in.^{3}).

In this particular instance, the chamber volume equals the propellant volume.

Substituting the required ballistics into equation 1 generates the following identity:

$$3{,}650\ \frac{ft}{sec} = \left[3213\left(\text{Log}\ \frac{c}{5000}\right) + 4120\right]\left[0.545(60)^{0.148}\right]\left[0.668\left(\frac{\frac{\pi}{4}\left(\frac{30}{25.4}\right)^2(84) + Vp}{Vp}\right)^{0.25}\right].$$

Since $c = \rho Vp$, where ρ = consolidated propellant charge loading density (gr/in.^{3}),

$c = 316.12\ \frac{gr}{in.^3}\ (Vp)$; the above identity becomes

$$3{,}650\ \frac{ft}{sec} = \left[3213\left(\text{Log}\ \frac{316.12\ (Vp)}{5000}\right) + 4120\right]\left[0.545(60)^{0.148}\right]\left[0.668\left(\frac{\frac{\pi}{4}\left(\frac{30}{25.4}\right)^2(84) + Vp}{Vp}\right)^{0.25}\right],$$

where the value of Vp is to be determined. Because of the complexity of the equation, the value of Vp will be determined by an iterative solution. If one assumes Vp to be 93.4 cm^3 (5.7 in.^{3}), then the right side of the equation equals 1,116 m/sec (3,661 ft/sec), which is only 3 m/sec (11 ft/sec) greater than the desired muzzle velocity of 1,113 m/sec (3,650 ft/sec). Therefore, a Vp of 93.4 cm^3 (5.7 in.^{3}) will be used for further calculations involving a 324 g (5000 gr) projectile.

Since 356.39 g (5500 gr) projectiles are used in the current TP and HE cartridges for the GAU-8/A, the analysis will be extended to include a 356.39 g (5500 gr) projectile with the 30 mm ballistic constraints. Substituting the ballistic parameters into equation 1,

$$3{,}650\ \frac{ft}{sec} = \left[3213\left(\text{Log}\ \frac{316.12\ (Vp)}{5500}\right) + 4120\right]\left[0.545(60)^{0.148}\right]\left[0.668\left(\frac{\frac{\pi}{4}\left(\frac{30}{25.4}\right)^2(84) + Vp}{Vp}\right)^{0.25}\right],$$

wherein Vp must again be determined. Assuming a Vp of 114.73 cm^3 (7.0 $in.^3$) (again an iterative solution), one finds that the right side of the equation equals 1,124 m/sec (3,688 ft/sec), which is 11 m/sec (38 ft/sec) greater than the desired muzzle velocity. Thus, the 356.39 g (5500 gr) computations will require a propellant volume of 114.73 cm^3 (7.0 $in.^3$).

General Solution of Minimum Cartridge Case Weight

Since the required propellant volumes have been calculated, a general solution will be derived to determine the minimum weight cartridge case (cylindrical configuration), capable of containing the predetermined fixed propellant volume. The cylindrical configuration to be minimized is illustrated in figure 1.

The definitions and equations detailed below will be used to derive the general solution.

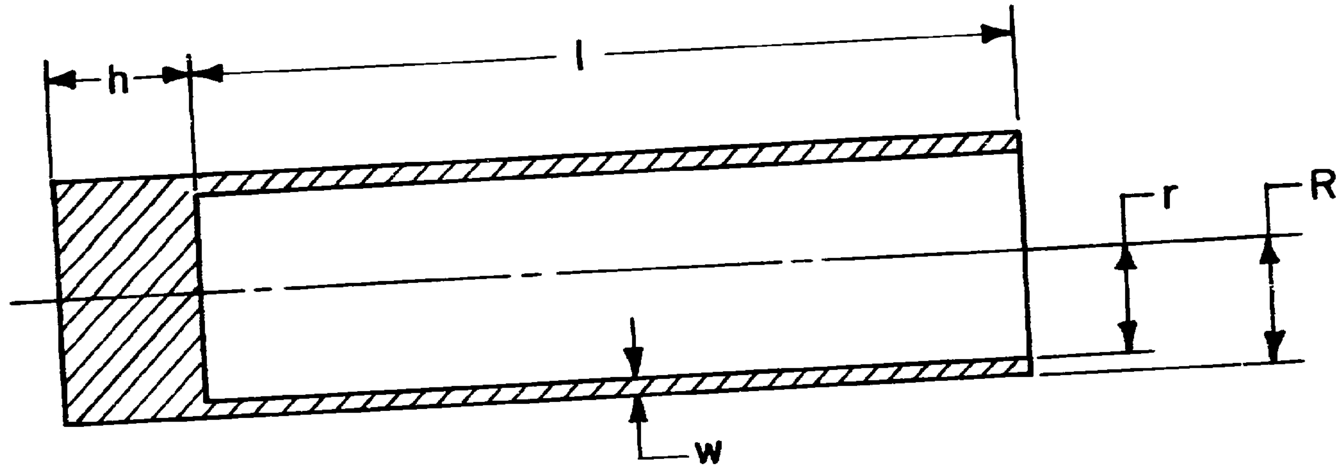
r	=	Propellant charge radius
R	=	Outside cartridge case radius
w	=	Wall thickness = R - r
h	=	Head thickness
l	=	Propellant charge length
Vp	=	Propellant volume (a constant) = $\pi r^2 l$
V_a	=	Head volume = $\pi R^2 h$
V_b	=	Wall volume = $\pi(R^2 - r^2)l = \pi l\ (R-r)\ (R+r)$
Vr	=	Total cartridge case volume = Va + Vb

The derivation is initiated by the defining of the following equation:

$$x \equiv \pi R^2$$

and

$$y \equiv 2\pi Rl + 2\pi rl.$$



LEGEND

R = OUTSIDE CASE RADIUS
r = INSIDE CASE RADIUS
w = WALL THICKNESS
l = PROPELLANT CHARGE LENGTH
h = HEAD THICKNESS

Figure 1. Cylindrically configured cartridge case.

Using the previously mentioned definitions, one obtains the following equation:

$$\frac{Va}{x} = \frac{\pi R^2 h}{\pi R^2} = h.$$

Similarly,

$$\frac{Vb}{y} = \frac{\pi l(R-r)\ (R+r)}{2\pi l\ (R+r)}.$$

Therefore,

$$Vb = \frac{yw}{2}.$$

Combining Va and Vb, one is able to define the total cartridge case volume as shown below:

$$Vt = xh + \frac{yw}{2}.$$

Substituting the appropriate definitions into the above equation, one obtains the following equation:

$$Vt = \pi wl\ (R+r) + \pi R^2 h. \tag{2}$$

Since $l = \frac{Vp}{\pi r^2}$, substituting for l in equation 2, one finds that

$$Vt = \frac{\pi wVp}{\pi r^2}\ (R+r) + \pi R^2 h.$$

By definition, $r = R - w$; after cancellation and substitution, equation 3 is obtained

$$V_t = wVp\ (2R-w)\ (R-w)^{-2} + \pi hR^2. \quad (3)$$

By evaluating and rearranging the first derivative of equation 3, the general solution, used to minimize the total cartridge case volume, is given by

$$\frac{-2w\ Vp\ (2R-w)}{(R-w)^3} + \frac{2w\ Vp}{(R-w)^2} + 2\pi hR = 0\ . \quad (4)$$

After multiplying both sides of equation 4 by $\frac{(R - w)\ (R - w)^2}{2}$, multiplying grouped terms and combining yields the following equation:

$$(R-w)^3 = \frac{w\ Vp}{\pi h},$$

or

$$R = \sqrt[3]{\frac{w\ Vp}{\pi h}} + w\ . \quad (5)$$

Thus, equation 5 is the general solution for the minimizing of the total cartridge case volume.

Minimum Weight Cartridge Case Calculations for 30 mm SLAMMO System

Since the propellant volumes have been defined as 93.4 cm^3 (5.7 $in.^3$) and 114.73 cm^3 (7.0 $in.^3$), two assumptions must be weighed before utilization of equation 5 for the 30 mm SLAMMO system. The first assumption is that the cartridge case wall thickness (w) will be defined as 0.10 cm (0.04 in.), as in the 30 mm AMCAWS configuration. The second assumption is that the cartridge case head thickness (h) will be eight times the wall thickness in this system; therefore, the head thickness will be 0.81 cm (0.32 in.) to provide sufficient metal to house the M115 primer and to affort adequate head strength.

Substituting the appropriate values into equation 5, one can determine R for a propellant volume of 93.4 cm^3 (324 gm projectile).

$$R = \sqrt[3]{\frac{(0.10\ cm)\ (93.4\ cm^3)}{\pi\ (0.81\ cm)}} + 0.10\ cm = 1.64\ cm\ (0.65\ in.)$$

Since R has been identified, the following dimensions can be calculated to determine the minimum weight cartridge case, while each dimension remains consistent with the 30 mm ballistic constraints previously established:

r = Propellant charge radius = R - w = 1.54 cm (0.61 in.)

l = Propellant charge length = $\frac{Vp}{\pi (r)^2}$ = 12.54 cm (4.88 in.)

L = Cartridge case length = l+h = 13.35 cm (5.20 in.)

d = Propellant charge diameter = 2(r) = 3.08 cm (1.22 in.)

D = Cartridge case diameter = 2(R) = 3.28 cm (1.30 in.).

Similarly, the minimized cartridge case and propellant charge dimensions can be computed for a propellant volume of 114.73 cm^3 (356.39 gm projectile).

$$R = \sqrt[3]{\frac{(0.10\ cm)\ (114.73\ cm^3)}{\pi\ (0.81\ cm)}} + 0.10\ cm = 1.75\ cm\ (0.69\ in.)$$

and the remaining case parameters are;

r = 1.65 cm (0.65 in.)

l = 13.41 cm (5.27 in.)

L = 14.22 cm (5.59 in.)

D = 3.50 cm (1.38 in.)

d = 3.30 cm (1.30 in.).

Thus far, a 324 gm (5000 gr) projectile requires a propellant volume of 93.4 cm^3 (5.7 $in.^3$) to satisfy the 30 mm ballistic constraints and to minimize the cartridge case weight. Since the fixed propellant volume has been defined as 93.4 cm^3 (5.7 $in.^3$), the cartridge case length to diameter (L/D) ratio will be varied to illustrate the effects that the permuting of the critical dimension (D) has on the normalized cartridge case weight. The propellant volume is defined as

$$V_p = \frac{\pi}{4} d^2 l .$$

Since d = D - 0.20 cm, l = L - 0.81 cm, and Vp = 93.4 cm^3,

the propellant volume can be written as

$$93.4 \text{ cm}^3 = \frac{\pi}{4} (D - 0.20 \text{ cm})^2 (L - 0.81 \text{ cm}). \qquad (6)$$

If the L/D ratio is varied from 1 to 7 in increments of 1, then D and L can be determined in equation 6 for each increment on the assumption of a fixed propellant volume of 93.4 cm^3 (5.7 $in.^3$). With the use of prior definitions, d and l can also be determined (table 1).

Table 1. Length and diameter determinations for cartridge case and propellant charge

L/D	D (cm)	D (in.)	d (cm)	d (in.)	L (cm)	L (in.)	l (cm)	l (in.)
1	5.33	2.10	5.13	2.02	5.33	2.10	4.52	1.78
2	4.18	1.64	3.97	1.56	8.36	3.29	7.54	2.97
3	3.64	1.43	3.43	1.35	10.91	4.30	10.10	3.98
4	3.30	1.30	3.10	1.22	13.21	5.20	12.39	4.88
5	3.07	1.21	2.86	1.13	15.33	6.03	14.52	5.71
6	2.89	1.14	2.68	1.06	17.33	6.82	16.51	6.50
7	2.75	1.08	2.54	1.00	19.22	7.57	18.41	7.25

With each L/D ratio, a new set of cartridge case and propellant charge parameters has been generated. The dimensions in table 1, in conjunction with equations 7 and 8, allow for the determination of cartridge case weight, assuming that the density of aluminum (ρ) is 2.70 g/cm^3 (682.80 $gr/in.^3$).

$$\text{Case volume} = V_c = \frac{\pi}{4} (D^2L - d^21) \quad (7)$$

$$\text{Case weight} = W_c = \rho V_c \quad (8)$$

Table 2. Cartridge case volume and weight calculations

L/D	D (cm)	D (in.)	Vc (cm^3)	Vc ($in.^3$)	Wc (gm)	Wc (gr)
1	5.33	2.10	25.716	1.569	69.43	1071.31
2	4.18	1.64	20.963	1.279	56.60	873.30
3	3.64	1.43	19.848	1.211	53.59	826.87
4	3.30	1.30	19.619	1.197	52.97	817.31
5	3.07	1.21	19.733	1.204	53.28	822.09
6	2.89	1.14	20.012	1.221	54.03	833.70
7	2.75	1.08	20.356	1.242	54.96	848.04

The data gleaned from tables 1 and 2 are illustrated in figures 2 and 3 in which constant propellant volume (Vp) has been maintained. As shown in figures 2 and 3, the cartridge case weight has been minimized at the L/D ratio of 4, where the case diameter is 3.30 cm (1.30 in.).

DISCUSSION OF RESULTS

From a historical vantage point, on the average, the 20 mm to 40 mm family of ammunition is characterized by an L/D ratio of 4. This contention is evidenced in table 3, wherein the length and diameter measurements were obtained from existing cartridge cases.

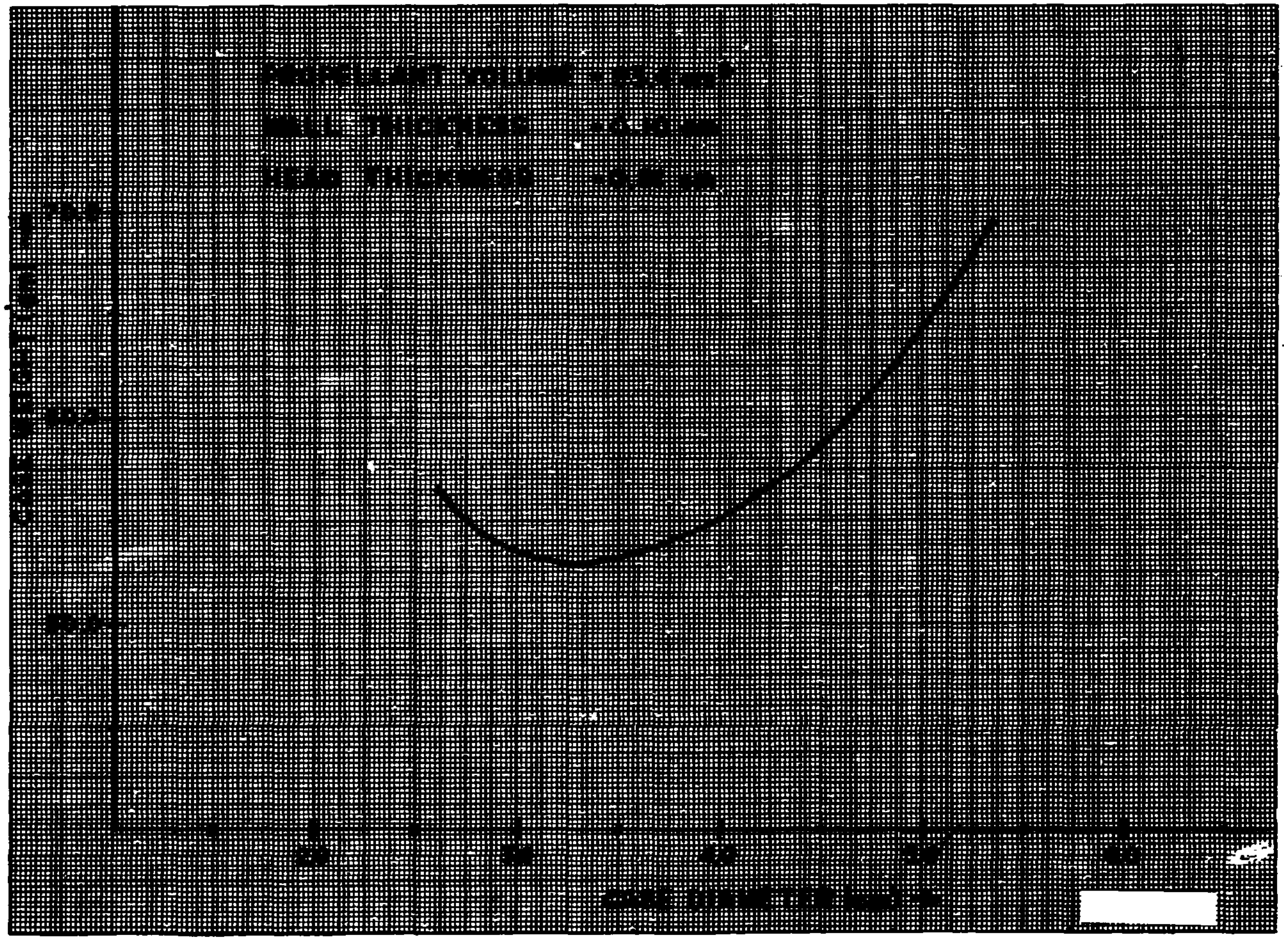


Figure 2. SLAMMO aluminum cartridge case weight versus case diameter.

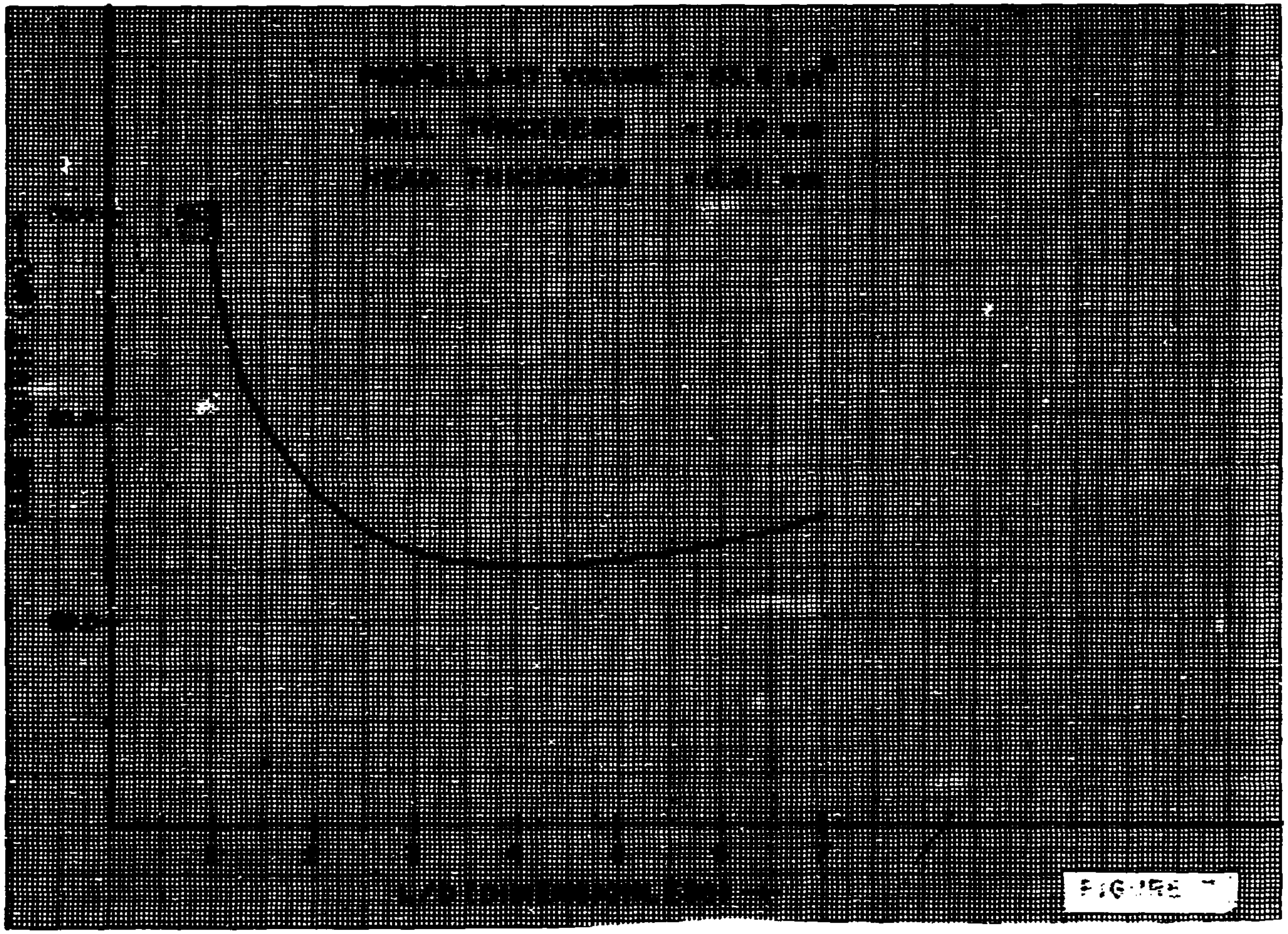


Figure 3. SLAMMO aluminum cartridge case weight versus length to diameter ratio.

Table 3. Length and diameter measurements for existing 20 mm to 40 mm cartridge cases

Caliber (mm)	Cartridge	Case length (cm)	Case length (in.)	Case diameter (cm)	Case diameter (in.)	L/D
20	M103	10.0	4.0	3.5	1.4	2.9
20	HSS820	13.7	5.5	3.5	1.4	3.9
25	Oerlikon KBA	13.7	5.5	3.7	1.5	3.7
30	Oerlikon 304 KCA	17.0	6.8	4.7	1.9	3.6
35	Oerlikon KDA	22.5	9.0	5.2	2.1	4.3
37	Vigilante	21.5	8.6	5.5	2.2	3.9
40	Bofors L/70	36.0	14.4	6.2	2.5	5.8
Average						4.0

Thus, an L/D of 4 for the minimum weight SLAMMO cartridge case is in accord with the historical development of cartridge cases.

With respect to the manufacturing of cartridge cases, the rather simplified design - straight side walls, minimum head thickness, and rolled mouth seal - should easily accommodate itself to fabrication by either extrusion or drawing operations. Moreover, since no extractor groove nor mouth crimp exists, the projectile insertion, mouth-annealing, and necking operations are absent; thus, the cost of the SLAMMO case should be less than the conventional case. The straight walled geometry of the SLAMMO case is also very amenable to loading with a consolidated propellant charge. The consolidated propellant charge can be fabricated in the case - an aggregate of propellant and solvent poured into the case and consolidated under a static load - or fabricated outside the case, in wafer form, and simply dropped into the case. Heretofore, in-case propellant consolidation was not possible in a bottleneck type cartridge case due to the differences in the case mouth and body diameters. A punch inserted into the case mouth would not exert uniform pressure over the entire surface of the propellant charge.

Two basic refinements to the cartridge case can be effected to improve the case design. First, the cartridge case should be tapered so that the forward (mouth) diameter is larger than the rear (head) diameter. This reverse taper will facilitate the chambering process provided the cartridge is inserted into the chamber with the aft portion first. Second, the head thickness was designed deep enough to house the M115 primer. Certain portions of the base can be eliminated; thus, cartridge case weight is reduced. A shortened cartridge case is also an advantage since the chambering and ejection stroke of the weapon is correspondingly shortened. Overall reduction in weapon system length serves to make the system more compact and will correspondingly reduce the total weight.

CONCLUSIONS

For the 30 mm ballistic requirements set forth, the recommended cartridge case configurations are given in table 4. These dimensions will yield the minimum weight cartridge case for the 30 mm SLAMMO system.

Table 4. Recommended cartridge case configurations

	324 g (5,000 gr) Projectile (cm)	(in.)
Length	13.35	5.20
Diameter	3.28	1.30
Wall thickness	0.10	0.04
Head thickness	0.81	0.32

	356.39 g (5,500 gr) Projectile (cm)	(in.)
Length	14.22	5.59
Diameter	3.50	1.38
Wall thickness	0.10	0.04
Head thickness	0.81	0.32

RECOMMENDATIONS

Propellant charges should be developed to conform to the internal dimensions of the minimum weight cartridge case. This development would include the selection of the proper web, deterrent, ignition system, and consolidation parameters. Ballistic evaluation of these propellant charges should be undertaken to assess the interior ballistic performance of these charges. The acceptable performance of the combination of minimum weight cartridge case and optimized propellant charge is the only realistic evaluation of the SLAMMO configuration.

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